Team Reports: University of California, Berkeley

University of California, Berkeley
Executive Summary
Principal Investigator: Jill Banfield

Biomars Report of Activities for the Period June 2003–June 2004.

Biomars members: Principal investigators: Jillian F. Banfield (PI). Co–investigators: Janice Bishop, Kristie Boering, Kevin Cuff, William Dietrich, David Emerson, George Luther III, Michael Manga, Eric Roden, Herb Their, Mark Kim (PARC). Coordinator: Javiera Cervini–Silva

BioMARS Education and Public Outreach (EPO) efforts . Kevin Cuff and Herb Thier (University of California at Bekeley and Lawrence Hall of Science)

Our efforts have focused on gathering information from local science educators, secondary school students, and BioMARS scientists that will ensure that resultant educational materials are unique, effective, and truly useful in both formal and informal educational settings locally and nationally. This process has included convening numerous focus group meetings at local high schools and Lawrence Hall of Science. At an early focus group meeting, which was used to gauge local student and teacher interest in proposed EPO activities, BioMARS project leader, Jill Banfield, made a presentation that provided an overview of the project's scientific aims, as well as the nature of her own project–related work. We have also worked on the development of hands–on instructional materials that provide opportunities for students to explore standards–based science concepts directly related to investigations that BioMARS PIs are engaged in (e.g. heat transfer and its relation to subsurface fluid transport), and enable students to develop a better overall understanding of the nature of science. These materials include inquiry–based activities that use the research of BioMARS' scientists to highlight and illuminate how important investigation design and detection systems are to BioMARS research in particular and, by extension, how these two elements are fundamental to all scientific research. Effectiveness of these activities has been assessed through a series of preliminary field tests with high and middle school students at local middle schools and community centers.

Spectroscopic Characterization of Martian Rocks Analogs. Janice L. Bishop (SETI Institute)

We acquired the NASA Langley ASD visible/near–infrared (VNIR) field

spectrometer and have tested it out on several rocks and minerals. Preliminary samples measured include a variety of sulfate minerals, acid mine drainage materials and some other Fe− and S−bearing samples. We are in the process of developing a library with this spectrometer for comparison of spectra collected in the field.

High quality reflectance spectra were measured at the NASA−supported Brown University Reflectance Experiment Lab (RELAB) of an acid mine drainage precipitate containing the minerals gypsum and ferrihydrite and a crystalline rock composed of the hydrated iron sulfate mineral rozenite that were collected at the Iron Mountain site in CA. These spectra were analyzed and compared with VNIR and mid−IR spectra of minerals and convolved to the spectral parameters of Martian Pathfinder, Pancam and mini−TES spectra. Emittance spectra and Mössbauer spectra were also measured of these samples by colleagues. Analyses of the Martian rocks and soil were preformed in comparison with these samples and it was shown that hydrated iron sulfate minerals such as the rozenite collected at Iron Mountain are consistent with many of the spectral and chemical properties of the global Martian dust observed currently at Gusev Crater and previously at the Pathfinder landing site. These results were reported at the Abscicon 2004 meeting (Bishop and Banfield, 2004) and a paper on this work is currently in progress.

Metal cycling, Microbes, and Organic Biomolecules. Jillian F. Banfield, William Dietrich, Michael Manga, Javiera Cervini−Silva (University of California at Berkeley), and Janice Bishop (SETI Institute). Organisms adapted to both acidic and neutral pH environments participate in iron and sulfur cycling. We have explored the role of extracellular polymers associated with neutrophilic iron−oxidizing bacteria in templating the crystallization of iron oxyhydroxide minerals with novel morphologies. Our results show that alginate−like organic threads accumulate a poorly crystalline precipitate and direct the growth of curved pseudo−single crystals of an unexpected structure, akaganeite, with very large aspect ratios (Chan et al.). These materials would not be expected in the absence of biological templates. At very low pH, we have studied the assembly of subsurface microbial communities sustained by iron oxidation. We have used culture−independent methods to investigate the abundance, distribution, and metabolism of an unexpected archaeal member that cannot be detected using typical PCR−based approaches. We have also explored the interactions between organic polymers and mineral surfaces and discovered new pathways for both depolymerization and polymerization of organic carbon compounds (Cervini−Silva and Banfield (in review); Cervini−Silva et al. (in review)).

Microbially−Mediated Sulfur and Iron Cycling . George Luther (University of Delaware), Jill Banfield (University of California at Berkeley), David Emerson (George Mason University) and Eric Roden (University of Alabama). With Dr. Banfield's group we have studied the mechanism of polythionate oxidation at low pH, which is facile with hydroxyl radicals formed on pyrite surfaces (Druschel et al, 2003). With Dr. Roden's group, we have investigated bacterial redox cycling at the oxic−anoxic interface with the neutrophilic Fe(II)−oxidizing bacterium strain TW2 and one paper is in press (Roden et al, 2004). With Dr. Emerson's group we have investigated the biotic oxidation rates of Fe(II) using

the isolate ES−1 obtained from the Fe(II) seep at Contrary Creek, VA. The biotic oxidation rate is significant under microaerobic conditions (< 20 µm O_2) and cannot be distinguished from the abiotic rate above 20 µm O_2. We have also discovered using our *in situ* solid−state voltammetric electrodes that FES_{aq} and $FeMnS_{aq}$ clusters are present in the environment (e.g., Fe(II) seeps), indicating that the sulfur cycle is intimately tied to the Fe cycle in fresh water environments. This and other Fe work were presented in Luther (2004) and Trouwborst et al (2004).

We are now designing a method with Dr. Emerson to use our electrodes to determine potential *in situ* Fe−oxidizing activities that can have broad applications in the field and in the lab. We plan further field research with the Biomars group and laboratory work exploring Fe cycling with microbial organisms with Drs. Emerson and Roden.

Neutrophilic Fe−oxidizers: Habitats, Distribution, and Physiology . David Emerson (George Mason University).

In addition to strains already in hand, we have begun new enrichment cultures from Fe mats located at the Loihi Seamount near Hawaii, the Eifuku Seamount near Guam, and the Soufriere hot spring system on the island of St. Lucia. This latter site is especially interesting because there are 50°C thermal springs there that show significant signs of microbial Fe−oxidation.

Melissa Floyd, a graduate student in the lab, has been developing a laboratory microcosm system that simulates conditions that occur in natural Fe−springs. The initial engineering challenge of maintaining suitable concentrations of Fe(II) under microaerobic conditions at neutral pH has nearly been met. This system will allow us to address questions about the physiology and molecular ecology under controlled conditions in the laboratory. Once the system is fully functional we intend to carry out model−testing experiments with the help of Dr. Roden.

Project Members : David Emerson (George Mason University), Ph.D, Co−Investigator, Research Scientist, ATCC; Robin Sutka, Ph.D, postdoctoral (through Sept. 2003), Melissa Floyd (current graduate student, George Mason Univ.), Cynthia Lydell (technician, ATCC, partial support from NAI)

Towards Isotopic Determinations on Martian Meteorites. Don DePaolo (University of California at Berkeley).

Work has begun on evaluating isotopic signatures of life and hydrological processes on Mars, with specific focus on Ca and Fe isotopes. For Ca isotopes there is a need to better constrain the equilibrium isotopic partitioning associated with inorganic processes to better assess evidence for organic fractionation. Two experiments are in progress. In one, calcite will be grown and equilibrated with dissolved carbonate in the laboratory at temperatures between about 10°C and 70°C (C and O isotopes will be measured as well to assess kinetic effects). The materials for this experiment are being assembled and the experiment design worked out. The second approach will be to use a natural terrestrial system where dissolved carbonate and solid calcite are expected to be in equilibrium. The system chosen is pore water in a deep−sea

sediment made up mostly of carbonate ooze. Samples have been obtained and analyses are in progress. A substantial effort is also underway to improve the precision of measurement of Δ^{44} Ca using a new multi−collector thermal infrared multispectral scanner (TIMS) instrument. We are collaborating with Will Dietrich and Michael Manga (below) to evaluate the origin of Martian channels by studying box canyons on the Snake River Plain. Samples have been collected and sample preparation has begun to establish the age of one canyon using cosmogenic He. In the coming year, the work already started will be continued, and in addition we will be working on Ca and Fe isotopes in volcanic hot and cold springs to characterize these environments, and making measurements on Martian meteorites.

Interaction between the geodynamic and hydrologic processes on Mars. Michael Manga. (University of California at Berkeley). We have developed experimental and numerical models for the evolution of mantle convection on Mars (Wenzel et al., Geophysical Research Letters, 2004). These models predict the spatial and temporal evolution of heat flow, which in turn are the critical boundary conditions for hydrothermal processes in the crust. We have also started to develop numerical models to study the hydrothermal processes that occur when magma is intruded into the cryosphere. We have used surface observations to better constrain the distribution and amount of water present in the Martian subsurface. We have shown that recent floods at Cerberus Fossae can be explained by discharge from aquifers (Manga, Geophysical Research Letters, 2004).We have also studied experimentally the mobility of granular mass flows in order to reevaluate the potential role of water in mass wasting on Mars. We find that unusually large run−out distances of granular flows can be explained only by the presence of interstitial fluids such as liquid water. Project members : Yoshiko Ogawa (postdoc: hydrothermal processes in the Martian crust), Bruno Cagnoli (postdoc: mobility of granular flow and the evidence for water on Mars), Mark Wenzel (graduate student: mantle convection on Mars), Veronika Soukhovitskaya (undergraduate: mobility of granular flow and the evidence for water on Mars), and collaborations with Curt Oldenburg at the Lawrence Berkeley National Laboratory (LBNL) on the numerical modeling.

Early Mars Atmosphere . For the atmospheric photochemistry experimental work exploring how the formation of aerosol in the atmosphere of early Mars may have had a dramatic influence on climate and habitability (Co−PI Boering), a more sensitive quadrupole mass spectrometer was purchased and incorporated into the existing experimental apparatus for studying the kinetics of formation and optical properties of atmospheric aerosols in the laboratory. Recent experimental results from this year were presented by graduate student Mate Adamkovics (supported by NAI funds) in a talk at NASA's Third Astrobiology Conference in April 2004 in which we found that particle formation by ultraviolet illumination can occur at considerably lower CH_4 −to− CO_2 ratios than predicted by photochemical models, a result that may mean that organic aerosols may have had a larger influence on the climate of early Earth and early Mars than previously estimated.

Project members : In addition to the continuing experimental work at UC Berkeley, collaborations are currently underway with R. Zare (Stanford) and G. Cooper (NASA Ames) to study the polycyclic aromatic hydrocarbon (PAH)

composition and the 13 C isotopic composition of the particles formed, respectively.

PUBLICATIONS

PEER−REVIEWED

Bishop, J.; Banfield, J.F. Spectroscopic Analysis of Fe− and S−bearing Materials for Remote Sensing of Biomarkers on Mars (in preparation).

C. S. Chan, G. De Stasio et al., “Microbial Polysaccharides Template Assembly of Nanocrystal Fibres,” *Science* , ***303*** , 1656, (2004).

Cervini−Silva J and Banfield, J.F. Coupled redox and dissolution reactions at surfaces of phosphate minerals can impact carbon dioxide and humic acid production in soils. *Environ. Sci. Technol.* (in review)

Cervini−Silva, J; Fowle, D.A.; Banfield, J.F. Biogenic dissolution of soil phosphate minerals. *Am. J. Sci.* Special Issue on Biogeochemistry (in review)

Druschel, G., D. Emerson, B. Glazer, C. Kraiya, R. Sutka and G. W. Luther, III. 2004. Environmental limits of the circumneutral iron−oxidizing bacterial isolate ES−1: Field, culture, and kinetic results from voltammetric analyses. *Geochimica Cosmochimica Acta* Vol. 68 (11S), p. A387.

Druschel, G. K., R. J. Hamers, G. W. Luther, III, and J. F. Banfield. 2003. Kinetics and mechanism of trithionate and tetrathionate oxidation at low pH by hydroxyl radicals. Aquatic Geochemistry 9, 145−164.

Emerson, D, and J.V. Weiss. Bacterial iron oxidation in circumneutral freshwater habitats: findings from the field and the laboratory. *Geomicrobiol. J.* In Press.

Luther, III, G.W. 2004. Geochemical Society − Patterson Medal Lecture: Exploring biogeochemical environments using in situ electrochemistry. *Geochimica Cosmochimica Acta* Vol. 68 (11S), p. A25.

Manga, M. (2004) Martian floods at Cerberus Fossae can be produced by groundwater discharge, Geophysical Research Letters, vol. 31, L02702, doi:10.1029/2003GL018958. Manga, M. and J.W. Kirchner (2004) Interpreting the temperature of water at cold springs and the importance of gravitational potential energy, submitted to *Water Resources Research* , vol. 40, W05110 10.1029/2003WR002905.

Roden, E.E., Sobolev, D., Glazer, B., and Luther, G.W. 2004. Potential for microscale bacterial Fe redox cycling at the aerobic−anaerobic interface . *Geomicrobiology Journal* , in press.

Wenzel, M.J., M. Manga, and A.M. Jellinek (2004) Tharsis: A consequence of Mars' dichotomy and layered mantle, *Geophysical Research Letters* vol. 31, L04702, doi:10.1029/2003GL019306.

Abstracts

Bishop, J.L. & Banfield J.F. (2004). Spectroscopic Analysis of Fe− and S−bearing Materials for Remote Sensing of Biomarkers on Mars. *Astrobiology Conference* 2004 (p.86).

Cervini−Silva J, Fowle D, Banfield J. Biogenic dissolution of soil phosphate minerals. Session on Microbial Impacts on Clay Transformation and Reactivity, 41st Annual Meeting of The Clays Minerals Society, Richland, WA, June 19−24, 2004.

Druschel, G., D. Emerson, B. Glazer, C. Kraiya, R. Sutka and G. W. Luther, III. Environmental limits of the circumneutral iron−oxidizing bacterial isolate ES−1: Field, culture, and kinetic results from voltammetric analyses, presented at the 2004 *Goldschmidt Conference* , Copenhagen, Denmark, June 9, 2004.

Druschel, G.K., D. Emerson, B. Glazer, C Kraiya, R. Sutka, and G.W. Luther. Defining the environmental limits of the circumneutral iron−oxidizing bacterial isolate ES−1: Field, culture, and kinetic results from voltammetric analyses. *Goldschmidt Conference* , 2004.

Druschel, G., R. Sutka, D. Emerson, G. W. Luther, III, C. Kraiya, and B. Glazer. Voltammetric investigation of Fe−Mn−S species in a microbially active wetland profile, presented at the *GSA meeting* , June 2004.

Manga, M., and A. Sinton, Wax models of Europan tectonics, Workshop on Europa's icy shell: Past, present, and future, Lunar Planetary Institute [IS THIS CORRECT?] (LPI) contribution 1195, pages 46−47.

Trouwborst, R.E., G. Koch, G. Druschel, L. Shanks, G.W. Luther, III and B. Pierson. Hot spring microbial mats: A model for Precambrian Banded Iron Formations, presented at the NASA Astrobiology Science Conference, NASA Ames Research Center in Mountain View CA, March 30, 2004.

Sessions

Javiera Cervini−Silva:

Co−chair (with Jon Chorover, University of Arizona). Symposium on Molecular Biogeochemical Processes. American Geophysical Union. San Francisco, December 13−17, 2003.

Co−chair (with Hailiang Dong, Miami University). Symposium on Microbial Impacts on Clay Transformation and Reactivity. The Annual Meeting of The Clay Minerals Society. Richland, June 19−24, 2004.

Co−chair (with Stephan Kraemer (Eidgenössische Technische Hochschule Zürich (ETH−Zürich)) and James Fredrickson (William R. Wiley Environmental

Molecular Sciences Laboratory (EMSL)−Pacific Northwest National Laboratory (PPNL)) : Symposium on Interfacial Biogeochemical Processes. Goldschmidt Conference, Moscow, ID. June 2005.

EDITORIAL ACTIVITIES

Journal special issues

David Emerson has edited a special issue of Geomicrobiology Journal on Neutrophilic Fe−oxidizing Bacteria. This issue will appear in September 2004, and contains 5 articles that cover a wide range of topics related to neutrophilic Fe oxidizers.

Javiera Cervini−Silva is co−editing a special issue of Clays and Clay Minerals on Microbial Impacts on Clay Transformation and Reactivity. The issue will appear in February 2005 and contains 14 articles.